A COMPARISON OF TWO PRECISION REGISTRATION PROCEDURES

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THESIS

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ABSTRACT

This thesis is addressed to the problem of determining if the precision registration procedure currently being utilized by the Field Artillery is as accurate and economical as a procedure that has recently been proposed by the Gunnery Department at Fort Sill, Oklahoma. A comparison of the two procedures was performed through the use of a computer simulation model. Data from the simulation was analyzed and conclusions were drawn regarding the relative accuracy and economy of the two procedures.

TABLE OF CONTENTS

I.	INTRODUCTION	7
	A. BACKGROUND	7
	B. SCOPE AND OUTLINE OF THE THESIS	11
II.	THE MODEL OF THE CURRENT REGISTRATION PROCEDURE	12
III.	THE MODEL OF THE NEW REGISTRATION PROCEDURE	18
IV.	RESULTS	22
	A. TABULATED RESULTS	22
	B. DISCUSSION OF RESULTS	23
	C. VALIDITY OF THE MODELS	26
V.	CONCLUSIONS AND RECOMMENDATIONS	28
	A. CONCLUSIONS	28
	B. RECOMMENDATIONS	28
APPENDIX A:	PROPOSED PROCEDURE FOR PRECISION FIRING	30
APPENDIX B:	COMPUTER PROGRAM	34
BIBLIOGRAPHY		47
INITIAL DISTRIBUTION LIST		49
FORM DD 1473		51

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LIST OF FIGURES

Figure		
I	Average Radial Miss Distance	24

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I. INTRODUCTION

A. BACKGROUND

One of the basic requirements in employing field artillery firepower is that "field artillery doctrine demands the timely and accurate delivery of fire to meet the requirements of supported units." [Ref. 4] When an artillery round is fired at a target, lack of precision and accuracy lead to an undesired distance between the actual point of impact and the actual target location. The precision in firing rounds with a given gun setting is associaed with parameters of an assumed normal distribution of impact points. Precision is characterized by Probable Error in Range (PER) and Probable Error in Deflection (PED). These will be discussed in Chapter II. On the other hand, accuracy is a function of bias error. The sources of accuracy errors are numerous, but generally are classified as interior and exterior ballistics errors. Interior ballistics errors can result from factors such as interior tube wear or barrel curvature (droop), and exterior ballistics errors from factors such as wind direction or the rotation of the earth, to name just a few of the many that exist [Ref. 13]. A method of reducing the accuracy errors is the conduct of a precision registration.

The purpose of a registration, as described by Field Manual 6-40 [Ref. 4], "is to determine the firing data that will place the mean burst location of rounds fired with that data at a point of known location. Registration data is used to determine corrections which, when applied,

will compensate for the cumulative errors contained in survey, the firing chart, material, and non-standard atmospheric conditions." Because standard conditions rarely exist and errors, however small, are present in the survey and firing charts, a precision registration is usually conducted as soon as is practical once an artillery battery moves into a new location. The registration facilitates estimation of the amount of range error (over or short of the target) and deflection error (left or right of the target)[1], so that appropriate corrections can be applied to increase the accuracy of subsequent rounds fired. The center howitzer or gun in a battery, known as the base piece, does the firing in a registration. The target fired upon is called the registration point. The conduct of a registration is divided into two phases. The first is the adjustment phase. Here the forward observer calls for shifts in range using the bracketing procedure described in reference 4. He also corrects errors in deflection by calling for shifts onto the observer-target (OT) line. The second phase is the fire for effect phase. It will be discussed in Chapter II.

The registration procedure that is currently being used by all U. S. Army Artillery units and by many of the allied artillery units is outlined in detail in Chapter 19 of reference 4. It has been continuously in use

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[1]The registration can also estimate the error in height of burst when it is conducted using a time fuse. Registration with time fuse is not considered in this paper.

for over twenty years and throughout this paper will be referred to as the "current procedure." One reason for the longevity of this procedure is that it is "sound, and mathematically conforms to the dispersion and probable error characteristics in our ballistics" [Ref. 7]. However it has been found that because the current procedure is relatively complex, when compared with the standard area adjust type of fire request, an unusually large number of errors are incurred by personnel in the Fire Direction Center (FDC). A study conducted at the Field Artillery School, Fort Sill, Oklahoma, showed that, in using current procedures, at least one error was made in over 50% of the registrations studied [Ref. 8]. It is also the experience of the author that the complexity of the current procedure makes the training of FDC personnel difficult and time consuming.

At the present time there are at least two alternative procedures for precision registration that have been suggested as possible replacements for the current procedure. One proposal, suggested by Litton Industries, would completely replace the current procedure [Ref. 13]. A former student at the U. S. Naval Postgraduate School, Major William W. Breen, U. S. Army, wrote a thesis comparing the current procedure with a prototype of the Litton procedure [Ref. 2]. Breen concluded that, under certain circumstances, a procedure such as the one suggested by Litton could be more economical and accurate than the current procedure. The Litton procedure was specifically designed to be used in conjunction with an automatic data processing (ADP) capability such

as that now being added to the artillery, and that scheduled or envisioned to be added in the future. However, a major disadvantage of the Litton procedure is that it is not feasible to perform it using manual methods of computations [Ref. 13]. A second proposal was submitted to the Field Artillery School in 1967 by the Gunnery Department at Fort Sill [Appendix A]. This procedure, which is henceforth called the "new procedure," contains many features that are appealing to this author. While it is planned for use with the ADP capability, the new procedure can be performed, if necessary, using manual methods of computations. It is similar to the procedure currently used in area adjust types of fire missions, and therefore training requirements for the FDC personnel should be greatly simplified [Ref. 8]. Approximately 78% of the errors that occurred during registrations observed in the FDC study mentioned above were committed in performing an operation that is eliminated in the new procedure [Ref. 7]. In a small sample (26 registrations) of firing, it was found that less ammunition was used and the total time required to conduct the registration missions was considerably less (by more than four minutes) when using the new procedure as compared with the current procedure [Ref. 7]. The new procedure is a modification of the current procedure. The adjustment phase of both the current and new procedures is the same, but the fire for effect phases are quite different. This will be discussed in detail in Chapter III.

B. SCOPE AND OUTLINE OF THE THESIS

The purpose of this thesis is to compare the current registration procedure with the new procedure proposed by the Gunnery Department at Fort Sill. This comparison was obtained by developing computer models of both procedures, using Monte Carlo Simulation techniques. Measures of effectiveness of the simulated procedures were taken to be the average number of rounds fired and the average radial miss distances of each procedure at each of several fixed ranges. These averages were based on 1000 repetitions with each procedure for conducting a registration. Three fixed ranges were used: 4,000, 8,000, and 12,000 meters. Use of these ranges allowed a consideration of different firing characteristics on the two procedures. Averages based on 500 repetitions with each procedure at thirteen different ranges were used to determine the relationship between the PER and the radial miss distance. Weapons characteristics utilized in the models were those of the 155 millimeter howitzer [Ref. 5].

The model used for the current procedure is adapted from a model used in reference 2. Modifications and assumptions of the current procedure model are described in Chapter II. The new procedure, as modelled, is described in Chapter III. Suggestions for improving the new procedure are given in Chapter V, along with conclusions of the thesis. The results of the computer simulations and the analysis of these results are given in Chapter IV. A listing of the computer program used for both simulation models is given in Appendix B.

II. THE MODEL OF THE CURRENT REGISTRATION PROCEDURE

The comparison of the current and new registration procedures was conducted using output from computer simulation models. A model of the current procedure used in this thesis was developed in reference 2. This model was reviewed by a representative of the Department of the Army, the Gunnery Department, and Artillery Board, Fort Sill, Oklahoma, at the request of its author, Major William W. Breen. The replies received are listed as references 6, 10, and 15. A detailed description of the current procedure is available in Chapter 19 of reference 4 and a discussion is given in reference 2. Concentration in this chapter will be on changes in, and deviations from, the model developed in reference 2. Some of these changes were motivated by the reviews mentioned above; others were deemed by the author to be advantageous. The changes are discussed in detail below. Features common to both the current and new procedures will also be discussed in what follows.

The forward observer is an important element in the conduct of a registration. It is his responsibility to attempt to observe the burst of each round and make precise corrections of the miss distance based on his estimation of the range error and deflection error. The reference plane which serves as a basis for these estimates is described by an axis intersecting the observer's location and the target location (OT line), and an axis perpendicular to the OT line passing through the

target. The distance between the observer and the target is called the OT range. The line between the artillery battery and the target is referred to as the gun-target (GT) line. A major feature in modelling a registration procedure is a consideration of the forward observers' ability to locate, with respect to the target, the burst of each round fired in the registration. In Breen's model of the current procedure, the distribution of the forward observers' error was based on the actual location of each burst in relation to the target location. This error was assumed to be uniformly distributed from zero to fifty percent of the actual miss distance. In the present paper the distribution of forward observers' error is assumed to be dependent on the OT range. OT range is established at the beginning of each simulated registration and remains constant throughout that registration. Establishment of this OT range is accomplished by a transformation of a random Normal (0, 1) deviate to a Normal deviate with a mean of 3,000 meters and a standard deviation of 1,000 meters.[2] This transformed deviate is then truncated to achieve an OT range that randomly varies from 100 to 6,000 meters. It appears to the author that this is a reasonable approximation of the distribution of OT ranges encountered in practice.

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[2]The Normal (0,1) deviate and the Uniform (0,1) deviate are generated from a function subprogram base on Subroutines GAUSS and GRN from reference 12. Transformation of a Normal (0,1) deviate (X) to a normal deviate (Y) with a mean (MU) and a standard deviation (SIGMA) is accomplished by the formula:

Y = X * SIGMA + MU

It is accepted by many expert artillerymen that the mean of the observers' error is a linear function of the OT range [Ref. 10, 15]. This is accomplished in the models of both the current and new procedures by distributing the observers' error uniformly with a mean that is a linear function of OT range. A function subprogram is used to generate the observer error and is referred to in Appendix B as FUNCTION ERRFCN. There are two inputs to this subprogram, the OT range, and the actual miss distance in range or deflection of a given round. The OT range determines the mean percentage error as an increasing linear function. This percentage is multiplied by a Uniform (0,1) deviate and the actual miss distance to determine the actual error in meters. The sign of the resulting error is determined by another Uniform (0,1) deviate. The resulting distance is then added algebraically to the actual miss distance, thus simulating the selection of an estimate by an observer whose errors in judging miss distances are a function of his range from the target and the actual miss distances. Observer errors for range and deflection are computed separately by this subprogram. A modest sensitivity analysis on observers' errors was performed using the simulation models. The results will be discussed in Chapter IV.

The model of the adjustment phase of the registration is identical in both the current and the new procedure, except for one feature. In the current procedure, adjustment continues until a burst splits a 100 meter bracket (200 meters if the PER exceeds 37.5 meters), whereas in the new procedure, adjustment continues until a burst splits a 100 meter

bracket (200 meters if the PER exceeds 25 meters). Once this condition is satisfied, the fire for effect phase is entered. At this point the two procedures differ. In the current procedure, the FDC assumes control of the firing and the observer is only required to designate the quadrant in which each round lands. In the new procedure the observer continues adjusting as is outlined in detail in Appendix A.

The angle between the gun-target line and the observer-target line is referred to as Angle T. In this thesis, Angle T was assumed to be zero. Selection of zero Angle T greatly enhances the performance of the current procedure model. This will be amplified in the discussion that follows. A factor that is sensitive to Angle T is "doubtful" range sensings by the forward observer. A doubtful sensing is reported to the FDC when a round lands left or right of the target at a range that appears to the observer to be at the same range as the target itself. The number of rounds required in a registration is affected by the number of doubtful sensings.

All corrections made by the forward observer along the OT line must be transformed by the FDC to corrections along the GT line so that firing commands may be ascertained. The effect of zero Angle T is that no transformation is necessary because in that case the GT line coincides with the GT line. This means that rounds doubtful in range to the observer will be doubtful to the FDC. In the adjustment phase of both procedures the bracketing procedure requires positive range sensings at each end of the bracket. A doubtful sensing will generally cause the

observer to require an additional round that otherwise would not be necessary, in order to obtain these positive sensings. Likewise, in the fire for effect phase of the current procedure, where the requirement exists for observation of at least six rounds with usable (positive sensed) ranges, a doubtful sensing would be a wasted round. This phenomenon is also true in the new procedure, since positive sensings are also required in the new procedure. When Angle T is not zero, however, another problem is introduced. Positive range sensings by the observer can become doubtful upon transformation by the FDC. The larger the Angle T, the more likely the FDC is to obtain these doubtfuls. This is explained by the interaction of the probable errors with Angle T. Therefore, in the current procedure, non-zero Angle T allows the possibility of even more wasted rounds due to doubtful sensings, as compared with zero Angle T. However, in the fire for effect phase of the new procedure, firing is continued as in the adjustment phase. Therefore the only doubtfuls possible are those rounds that are sensed by the observer as doubtful. Hence, it may be concluded that the assumption of zero Angle T in the models of both procedures enhances the performance of only the current procedure.

Doubtful sensings by the observer are modelled in the adjustment phase of both procedures. The region associated with doubtful sensings was approximated by a cone with a central angle whose tangent is the range error of the burst divided by the deflection error. Doubtfuls were not modelled in the fire for effect phase of the current procedure model

due to the nature of the computer model being utilized from reference 2. It was anticipated that this would result in a conservative estimate for the number of rounds fired in a registration using the current procedure.[3] In the fire for effect phase of the new procedure model, doubtfuls are modelled as described above.

The degree of accuracy with which an observer can sense the location of a round is important for a realistic simulation. The current procedure requires that deflection corrections be made only to the nearest 10 meters. Accordingly, a function subprogram was added to the model of both procedures to round off the deflection corrections. Sensings by the observer were converted from real numbers to integer values because the observer is trained to make all sensings and corrections in an integer format. In addition, his ability to estimate to a precision of less than one meter is highly questionable.

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[3]It is the experience of the author that, in the fire for effect phase, an average of at least one round is sensed as doubtful in range.

III. THE MODEL OF THE NEW REGISTRATION PROCEDURE

Many features of the new registration procedure, particularly those that are in common with the current procedure, were discussed in Chapter II. A description of the new procedure, and a proposed change to Field Manual 6-40 with illustrative examples, is attached as Appendix A. The reader may find it helpful to read Appendix A before reading the discussion that follows. The new procedure, as modelled, is listed under SUBROUTINE NEW in Appendix B. As was previously mentioned, the fire for effect phase is completely changed in the new procedure over that used in the current procedure. The forward observer splits a 50 meter bracket (100 meter if PER exceeds 25 meters) and then continues to adjust the rounds according to the rules listed in Appendix A. "His objective is to obtain a minimum of two pairs of positive spottings 25 meters apart bracketing the adjusting point" [Appendix A]. In the model of the new procedure this objective was used as the criterion for termination of the registration.

To accomplish this objective two assumptions (in addition to those previously mentioned) were made concerning the new procedure in the development of the model. The first assumption is that the observer, or preferably the Reconnaissance Sergeant or Radio Telephone Operator, are recording certain data after each round is observed. The data that would be recorded are the observer's sensing of the range error and deflection error, and the observer's subsequent corrections,

which are based on these sensings. This record, which is necessary in the model of the new procedure, is presently not required, in the current procedure, except by some units for training purposes.* No loss in the time to complete a registration should result from this requirement. The algorithm that describes the new procedure in the fire for effect phase assumes that, after the fourth and subsequent rounds in that phase, the observer will scan the record of past data to make a determination of whether the criterion to end the registration is satisfied. Once he determines the registration is completed, he again uses the recorded data to make a final adjustment, should it be required.

The second assumption is merely an interpretation of the new procedure as described in Appendix A. It is the opinion of this author that the wording of Appendix A is somewhat vague as to the exact action to be taken by the forward observer after the fourth round in the fire for effect phase. If the criterion established in Appendix A is not satisfied after the fourth round, it is assumed in the model of the new procedure that the observer checks the previous two rounds to determine his course of action. If both rounds are sensed to be on the same side of the target, the next round is moved 25 meters (50 meters if the PER exceeds 25 meters) in the appropriate direction in order to reestablish the necessary bracket. If the previous two rounds bracket the target, the firing continues at the same range.

In the model of the new procedure the criterion utilized for successful termination of the registration was based on Appendix A. After completion of a major portion of the computer effort, correspondence was received from the Gunnery Department at Fort Sill [Ref. 9] that contained the following comment:

> "Although it is not properly stated in our article on the proposed procedure, the new procedure should allow the observer considerable latitude in deciding when a mission should be terminated. We do not want to force the observer to continue firing until he established a pair of overs and shorts within 'TEST' meters if he already has a 3-1 split (all fairly close to the target). In this case, we would probably want to end the mission and make a final correction to bring the mean point of impact of the 4 rounds to the target."

It was also suggested, by the Gunnery Department, that this be incorporated, if possible, in the present model of the new procedure. To include this additional and subjective constraint in the computer model would have required considerable effort in programming and computer time that were not available to this author. It is recommended, however, that this valuable extension be considered for further research into this topic. More important, in this author's opinion, was the effect on the results of the simulations of using the established criterion in lieu of the suggested additional criterion of the Gunnery Department. The criterion established for completion of the registration in this thesis is more restrictive without the suggested addition, and therefore should require not fewer rounds to be satisfied, as compared with the suggested criterion. The effect of this restriction on the

average radial miss distances is not easily determined. As the addition was suggested for application only when the four rounds are "fairly close" to the target, it is the belief of this author that no significant change in the miss distance would occur if the suggested criterion were used.

IV. RESULTS

A. TABULATED RESULTS

The tables below contain a sample of the results of a simulation of 1000 repetitions of each registration procedure at each of three ranges. The error function used in this sample allowed the observer error to vary from zero to 100% of the actual miss distance, with a mean observer error of 25% of the actual miss distance. "C" refers to the current procedure, and "N" refers to the new procedure as discussed previously in this thesis.

Range: 4000 PER: 16.00 PED: 1.00

	Rounds Used	Average Miss Distance	Standard Deviation in Number of Rounds	Standard Deviation in Miss Distance
C	10.21	12.73	0.46	8.76
N	10.45	7.06	2.23	5.70

T Statistic:(Miss Distance): -17.2 Degrees of Freedom: 1718

Range: 8000 PER: 31.00 PED: 2.00

	Rounds Used	Average Miss Distance	Standard Deviation in Number of Rounds	Standard Deviation in Miss Distance
C	10.23	22.59	0.51	15.87
N	9.28	14.63	2.14	14.66

T Statistic: -11.6 Degrees of Freedom: 1988

Range: 12000 PER: 42.00 PED: 4.00

	Rounds Used	Average Miss Distance	Standard Deviation in Number of Rounds	Standard Deviation in Miss Distance
C	9.24	33.26	0.50	23.00
N	9.41	22.08	2.69	21.35

T Statistic: -11.3 Degrees of Freedom: 1989

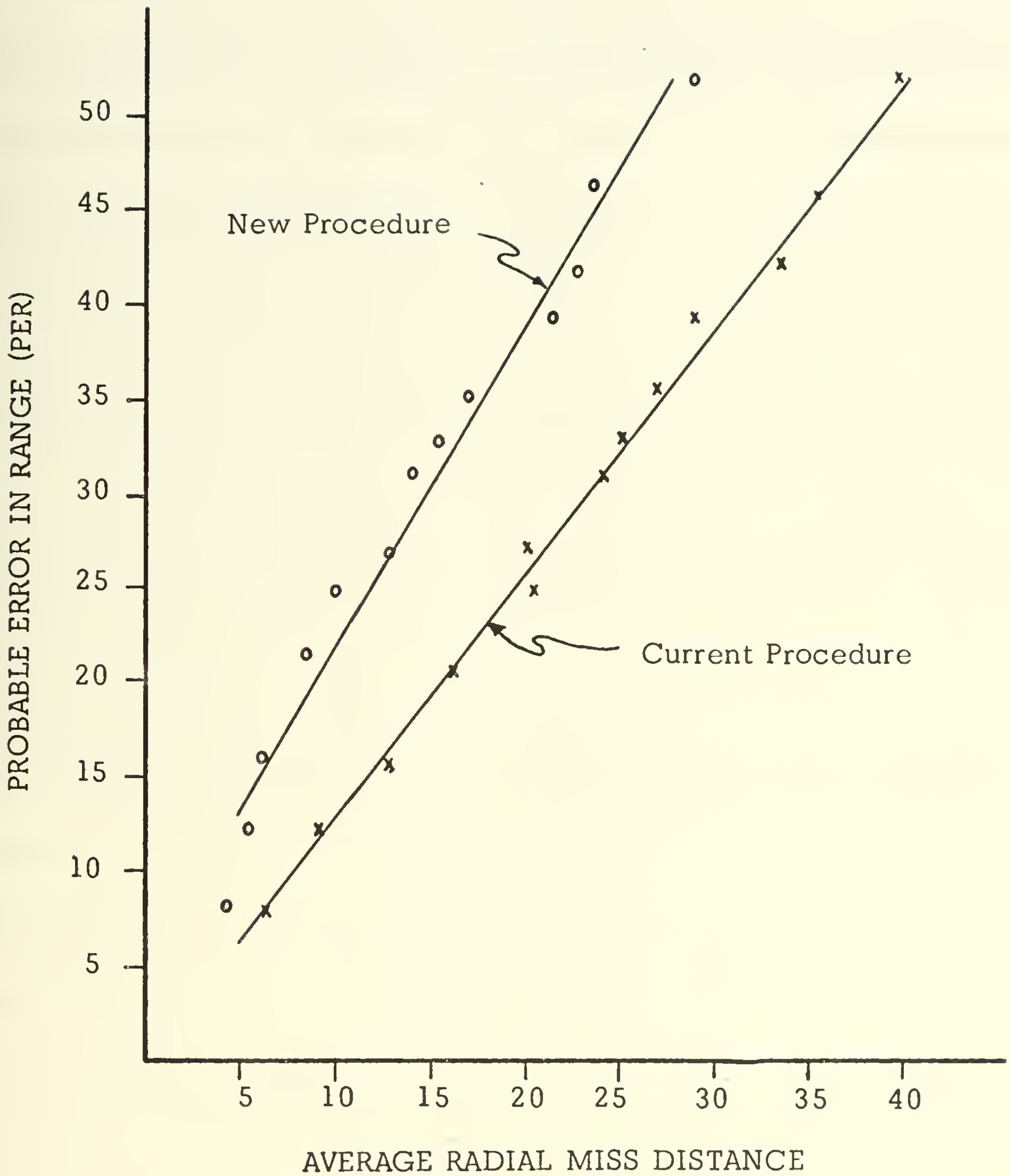
The following table contains the results of thirteen simulations of 500 repetitions of each registration procedure at the ranges noted. The error function described in previous results was used. A graphical representation of the data in this table is shown in Figure I.

Procedure						
			Current		New	
Range	PER	PED	Rounds Used	Average Miss Distance	Rounds Used	Average Miss Distance
2000	8	1	10.48	6.28	9.84	4.93
3000	12	1	10.31	9.21	10.11	5.54
4000	16	1	10.22	12.95	10.47	6.25
5000	21	1	10.23	16.11	10.53	8.87
6000	25	2	10.24	20.61	10.84	10.28
7000	27	2	10.23	20.77	9.10	13.05
8000	31	2	10.28	24.19	9.16	14.91
9000	33	3	10.21	25.27	9.19	15.60
10000	35	3	10.27	27.17	9.36	16.83
11000	39	3	9.24	29.48	9.47	21.17
12000	42	4	9.24	33.52	9.42	22.25
13000	46	4	9.24	35.51	9.57	23.90
14000	52	5	9.35	39.91	9.98	29.02

B. DISCUSSION OF RESULTS

The average number of rounds used in the current procedure model is somewhat less than expected.[4] This was previously alluded to in Chapter II. The assumption of zero Angle T and the lack of doubtfuls in the fire for effect phase of the current procedure model account for this discrepancy. It also accounts for the lower standard deviation in

[4]It has been the experience of this author that the average number of rounds used in the current procedure varies between eleven and thirteen.



PROBABLE ERROR IN RANGE (PER)
50
45
40
35
30
25
20
15
10
5
New Procedure
Current Procedure
5
10
15
20
25
30
35
40
AVERAGE RADIAL MISS DISTANCE

Figure I

the number of rounds. Based on the results of the simulations and the effects of the assumptions as previously discussed, it is the opinion of this author that the new procedure as modelled uses approximately two rounds less than the current procedure as modelled. Analysis of the accuracy of the two procedures was performed using T-tests on the radial miss distances generated during each set of 1000 registrations. The results of these analyses are also obvious by inspection. The new procedure model performed significantly better in accuracy in all ranges tested. The lower standard deviation of the miss distances in the new procedure indicates more consistent performance at the tested ranges.

A modest sensitivity analysis was performed on the observers' error function discussed in previous chapters. The effect on the simulations of varying the error was studied using eight different error functions. They varied from zero average absolute error up to 100 percent average absolute error by the observer. The current procedure model was insensitive to changes in the error function. This appears to be because, in the current procedure, the function only applies during the adjustment phase, and then only to the deflection sensings. In the model of the new procedure the number of rounds used and the miss distance increased slightly as the observer error function increased. However, changes in the error function in no case altered the relative accuracy of the procedures. A similar comment may be made concerning the average number of rounds.

A number of central angles describing the region of the doubtful sensings were tested using the models of both procedures. The angles tested varied from zero to sixty degrees. Results confirm that the average number of rounds increase as the angle increases, but only by a slight amount. The change in average miss distance was insignificant, and no discernible pattern was evident. The results listed in the tables were all generated with a central angle of twenty degrees.

C. VALIDITY OF THE MODELS

As was found in reference 2, the average accuracy of the current procedure, as modelled, closely approximated that found in reference 11, Theoretical Study of Registration Procedures. The theoretical study mentioned above suggests that average miss distance attained with the current procedure is a linear function of the PER as described by the following formula:

$$\text{MEAN MISS DISTANCE} = (0.6558) * \text{PER} \qquad (1)$$

The results of the simulations with the current procedure model suggest that there is a linear relationship between average miss distance and PER, but the slope that described this relationship is slightly higher than that found in reference 11. Simple linear regression analysis of the simulation results suggests the following formula:

$$\text{MEAN MISS DISTANCE} = (0.7686) * \text{PER} - 0.2683 \qquad (2)$$

The higher slope in (2) can be at least in part attributed to the inclusion of some rounds that would have been sensed as doubtfuls,

were doubtfuls considered in the fire for effect phase. A round sensed as doubtful would have been refired with possibly a deflection correction applied, thus increasing the probability of the burst being located even closer to the target.

Due to the lack of sufficient experimental data on the new procedure, it was not possible to adequately test the validity of the results of the model's performance. It is the judgement of this author that the model's results are a fair representation of the procedure's capability. The results of the simulations with the new procedure model suggest that the relationship between average miss distance and PER is also linear. Simple linear regression analysis of the simulation results suggests the following formula:

$$\text{MEAN MISS DISTANCE} = (0.5848) * \text{PER} - 2.6088 \qquad (3)$$

The graphical representation in Figure I was drawn using (2) and (3) above.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The results from the computer simulation models clearly indicate that the new procedure proposed by the Gunnery Department at Fort Sill, Okalhoma, is probably more accurate than the procedure currently being utilized for precision registrations. Weighing the effects of the limiting assumptions in the model, which clearly enhanced the performance of the current procedure, this difference becomes even more evident. The same can be said for the average number of rounds used by each procedure.

B. RECOMMENDATIONS

It is recommended that the Gunnery Department consider experimentation to better approximate the ability of the forward observer to estimate the range to the target, and the deflection and range error of the bursts of subsequent rounds fired at the target. Target acquisition devices currently under development, designed to enhance the observer's ability, can be more accurately assessed as to their effectiveness if the observer's abilities are known.

It might also be possible that designing new gunnery procedures, specifically tailored for use with these devices, may prove to be cost-effective in lieu of proceeding to only an interim solution such as the proposal by the Gunnery Department appears to be. However, whatever

course of action is taken, the results from the above experimentation would prove useful in future analysis of candidate precision registration procedures.

The comment quoted in Chapter III indicated to this author that a rewriting of the proposed procedure is necessary in order to reduce the ambiguity that presently exists in the Gunnery Department description of the procedure in Appendix A.

The decisiveness of the differences in the accuracies of the two procedures suggests that thought and possibly research is warranted in determining if modifications of the proposed procedure can produce a better cost-effective procedure. The current procedure uses at least six rounds in the fire for effect phase to estimate the location of the registration point. The proposed procedure requires at least four rounds in this phase. The question that immediately comes to this author's attention is what are the results if one, two, three, or even a variable number of rounds are required? It is recommended that future studies of the precision registration procedure be capable of answering questions such as the above.

APPENDIX A

PROPOSED PROCEDURE FOR PRECISION FIRING

The proposed procedure is identical to the present procedure until the 50 M bracket is split (FFE phase begins). The destruction mission procedure will be similar to that of the registration mission and in both cases will be conducted with one gun.

The principal instructions for the new procedures are at the forward observer level. These are covered in detail below.

At the FDC level the change amounts to nothing more than a continuation of the adjustment procedure, moving the pin on the chart according to corrections given by the FO. The final location of the pin is the point at which the adjusted data are determined. In other words, the present FDC procedural requirements--i.e., use of S/2 card, spotting card to convert OT to GT spottings, record of precision fire, and a formula to determine adjusted elevation--are eliminated.

At the FO level, the FO continues to adjust the rounds, after splitting the 50 M bracket, according to the rules listed below. His objective is to obtain a minimum of two pairs of positive spottings 25 meters apart bracketing th adjusting point.

Depending on the spottings, there are several actions the observer can take after splitting the 50 M bracket, all of which are based on positive range spottings.

1. If the split of the 100 meter bracket provides positive spottings other than target or range correct, the FO splits the remaining 50 meter bracket by moving 25 meters in range in the appropriate direction. Firing continues at this split until two positive range spottings are obtained. Both of these rounds can result in the same spotting, they can be bracketing, or one or both can be target hits. Subsequent possible actions for these results are as follows:

a. If both rounds result in the same spotting (both short or both over), the FO requests ADD or DROP 25 and firing continues until two positive range spottings are obtained at the other end of the bracket. Based on his observations the FO may determine that either pair of bracketing rounds was very close to the adjusting point, or that a further correction of 10 meters is needed. For example, (1) if the last bracketing range fired was very close, he transmits END OF MISSION, RECORD ADJUSTED DATA, (2) if the pair at the other end of the bracket was close, he transmits ADD (or DROP) 25, END OF MISSION, RECORD ADJUSTED DATA, (3) if the adjusting point appears to be about an equal distance from each pair of bracketing rounds, he transmits ADD (or DROP) 10, END OF MISSION, RECORD ADJUSTED DATA.

b. If both rounds are bracketing over and short, firing continues and appropriate range changes made until a minimum of two pairs of positive range bracketing spottings are obtained. Spotting of

range correct or a target can be considered as both an over and a short. Based on his observations the FO may record adjusted data or move 10 or 25 meters.

c. If one of the rounds results in a target or range correct, firing is continued as in b above.

d. If both rounds result in a target or range correct, the FO may record adjusted data.

2. While in the adjustment, corrections to deviations are made to the nearest 10 meters for each off line shot. In the FFE Phase, corrections to deviation in 10 meter increments are made from the average lateral deviation of pairs of rounds. Obtaining and splitting of deviation brackets are encouraged, particularly when large angle T's exist.

3. The principle of verification of each positive spotting to secure pairs of positive bracketing spottings provides a strong deterrent to invalid registrations and the FO would be more apt to recognize it. For example, when large probable errors exist, or the observer obtained a false bracket prior to the split of the 50 meter bracket, the mission at the split of the 50 meter bracket could go as follows: ADD 25 (short); REPEAT (short); ADD 25 (short); ADD 25 (short, very close); ADD 25 (over); REPEAT (over); DROP 25 (short, very close), END OF MISSION RECORD ADJUSTED DATA.

4. In the above procedure certain precautionary rules must be observed:

a. Observer must be wary of making bold range spottings for bursts considerably off the OT line. For example, when the first round of the registration is spotted considerably off line and the observer believes that a 200 meter range change will bracket he must ignore the range change, make a deviation change only and attempt to get the round on or near line. The rule applies also at the split of the 100 meter bracket; if the result is off line and the observer is not absolutely certain of the range spotting, the round must be moved on or near line prior to splitting the 50 meter bracket.

b. The principles of dispersion must be considered by the FO. In the above procedure the movement of 25 meters is equivalent to 1/2 fork when the PE_r is 12.5 meters. When the PE_r is greater than 12 1/2 meters, the fork is also greater and there is a higher probability that small corrections by the FO will be inconsistent to the point where an add could produce no change or even result in a burst shorter than the previous one. Therefore, the observer must be informed when the PE_r is greater than 30 meters. In those cases, he will enter FFE when splitting a 100 meter bracket. Additional range changes are made in 50 meter increments. Without any special instructions the observer splits the 50 M bracket as outlined above.

APPENDIX B

COMPUTER LISTING OF SIMULATION MODELS

```
C
C        THE MAIN PROGRAM CONTROLS THE SIMULATION BY DESCRIBING
C     THE PARAMETERS TO BE USED THROUGHOUT, MAINTAINING A
C     COUNT OF MISSIONS FIRED, AND PERFORMING SOME GENERAL
C     CALCULATIONS.
C
         REAL MISDIS,MISS,IADDO,IADDN,OTRG
         DIMENSION MISS(1000),STAND(1000),IADDO(1000),IADDN(100
        A0)
         COMMON TABLE(50,6),OTRG,FIRST,FERST,RN,MISDIS,IADD,PER
        1,PED
C
C        INITIALIZE THE RANDOM NUMBER GENERATOR.
C
         START=RAN(-351)
         ICASE=-1
         SUM=0
         SUM2=0
         DIST=0
         DIFF=0
         SQMISS=0
         SQIADD=0
       1 IF(ICASE)2,3,4
C
C        DETERMINE PARAMETERS ASSOCIATED WITH TEST RANGES.
C
       2 RN=4000
         PER=16.00
         PED=1
         GO TO 5
       3 RN=8000
         PER=31.00
         PED=2
         GO TO 5
       4 RN=12000
         PER=42.00
         PED=4
       5 WRITE(8,100)RN,PER,PED
         ITEM=-1
C
C        START THE MISSION COUNTER.
C
      13 ICOUNT=0
      55 ICOUNT=ICOUNT+1
C
C        ESTABLISH THE OBSERVER-TARGET RANGE (OTRG)
C
      99 OTRG=RAN(0)*1000+3000
         IF(OTRG.LT.100.0) GO TO 99
         IF(OTRG.GT.6000) GO TO 99
C
C        ESTABLISH THE LOCATION OF THE FIRST ROUND FIRED IN THE
C     MISSION.  FIRST REFERS TO RANGE, FERST TO DEFLECTION.
C
```

```
      FIRST=RAN(1)*200+PER
      IF(RAN(1).LE.0.5) FIRST=FIRST-(2*PER)
      IF(RAN(1).GT..5) GO TO 6
      FIRST=-FIRST
    6 FERST=RAN(1)*100+PED
      IF(RAN(1).LE.0.5) FERST=FERST-(2*PED)
      IF(RAN(1).GT..5)GO TO 7
      FERST=-FERST
C
    7 IF(ITEM)8,9,9
C
C     CALL THE MODEL OF THE CURRENT REGISTRATION PROCEDURE.
C
    8 CALL OLD
      STAND(ICOUNT)=MISDIS
      IADDO(ICOUNT)=IADD
      GO TO 11
C
C     CALL THE MODEL OF THE NEW REGISTRATION PROCEDURE
C
    9 CALL NEW
      MISS(ICOUNT)=MISDIS
      IADDN(ICOUNT)=IADD
C
C     MAINTAIN RUNNING TOTALS FOR EACH PROCEDURE.
C
   11 SUM=SUM+IADD
      SUM2=SUM2+MISDIS
      SQMISS=SQMISS+MISDIS**2
      SQIADD=SQIADD+IADD**2
      IF(ICOUNT.LT.250)GO TO 55
      ITEM=ITEM+1
C
C     AFTER 1000 MISSIONS COMPUTE THE AVERAGES AND STANDARD
C    DEVIATIONS, ZERO THE RUNNING TOTALS, AND PRINT THE RESULT
C
      AV1=SUM/ICOUNT
      AV2=SUM2/ICOUNT
      SIGMA=SQRT(SQMISS/ICOUNT-AV2**2)
      SIGMA2=SQRT(SQIADD/ICOUNT-AV1**2)
      SQMISS=0
      SQIADD=0
      SUM=0
      SUM2=0
      WRITE(8,105)AV1,AV2
      WRITE(8,107)SIGMA
      WRITE(8,108) SIGMA2
      IF(ITEM.EQ.0)GO TO 12
C
C     IF THE NEW PROCEDURE HAS JUST BEEN FIRED 1000 TIMES,
C    CALL THE T-TEST FOR COMPARISON WITH STANDARD SET BY
C    CURRENT PROCEDURE.
C
      CALL TTEST(STAND,ICOUNT,MISS,ICOUNT,3,NDF,ANS)
      WRITE(8,109) NDF,ANS
      CALL TTEST(IADDO,ICOUNT,IADDN,ICOUNT,3,NDF,ANS)
      WRITE(8,109) NDF,ANS
   12 IF (ITEM.LT.1)GO TO 13
      ICASE=ICASE+1
      IF (ICASE.LE.1) GO TO 1
  100 FORMAT(1H1,18X,'RANGE:'F6.0,'METERS                    PER:
     A',F6.2, 'PED:',F6.2)
  105 FORMAT(//T7,' AVG ROUNDS USED:',F6.2,' AVG MISS DISTAN
     1CE:',F8.2)
  107 FORMAT(/,T7,' STANDARD DEVIATION OF MISS DISTANCE:',F8
     A.2)
  108 FORMAT(/,T7,' STANDARD DEVIATION OF NO. OF ROUNDS:',F6
     A.2)
  109 FORMAT(/,T7,' NUMBER OF DEGREES OF FREEDOM FOR T-TEST:
     A',I6,//,T7,' T STATISTIC:',F10.4)
      STOP
      END
```

```
C
C     THIS SUBROUTINE GENERATES UNIFORM OR NORMAL RANDOM
C  DEVIATES OVER(0,1).
C

      FUNCTION RAN(J)
C     FOR J LT 0 SET INITIAL VALUE OF GENERATOR
C     FOR J EQUAL 0 GENERATE NORMAL (0,1) NUMBER
C     FOR J GT 0 GENERATE UNIFORM (0,1) NUMBER
      IF(J.GE.0) GO TO 10
      IX=1-2*J
      X=0
      GO TO 150
   10 IX=IX*65539
      IF(IX.LT.0)IX=IX+2147483647+1
      X=FLOAT(IX)*.4656613E-9
      IF(J.NE.0)GO TO 150
      DO 100 I=1,11
      IX=IX*65539
      IF(IX.LT.0)IX=IX+2147483647+1
  100 X=X+FLOAT(IX)*.4656613E-9
      X=X-6.0
  150 RAN=X
      RETURN
      END
```

```
C
C     THIS SUBROUTINE DETERMINES THE FORWARD OBSERVER ERROR
C

      FUNCTION ERRFCN(X,Y)
      ERROR=X/6000*ABS(Y)*(RAN(1))
      IF (RAN(1).GT..5)GO TO 1
      ERROR=-ERROR
    1 ERRFCN=Y+ERROR
      RETURN
      END
```

```
C
C    THIS ROUTINE ROUNDS OFF INPUT TO NEAREST 10 METERS
C

      FUNCTION RDOFF(Y)
      N=IFIX(Y)/10
      IF(Y.LT.0.0) GO TO 5
      IF(IABS(IFIX(Y)-10*N).GE.5.0) N=N+1
      GO TO 7
    5 IF(IABS(IFIX(Y)-10*N).GE.5.0) N=N-1
    7 RDOFF=10*FLOAT(N)
      RETURN
      END
```

```
C        THIS SUBROUTINE MODELS THE CURRENT PRECISION REGISTRA-
C     TION TECHNIQUE.
C

         SUBROUTINE OLD
         REAL MISDIS,IUSE,OTRG
         INTEGER Z,Z2,RDIFF,SHORT,OVER
         LOGICAL LESS
         DIMENSION ADJ(20),SENSE(20),FFE(20),IUSE(10),WIDE(10),
        1WIDFFE(10)
         COMMON TABLE(50,6),OTRG,FIRST,FERST,RN,MISDIS,IADD,PER
        1,PED
C
C        ZERO ALL ARRAYS
C
         DO 22 I=1,10
         IUSE(I)=0
         WIDE(I)=0
      22 WIDFFE(I)=0
         DO 23 I=1,20
         ADJ(I)=0
      23 FFE(I)=0
         I=0
         J=1
         K=0
         N=1
         OVER=0
         SHORT=0
C
C        THE FIRST ROUND IS TAKEN AS SENT FROM THE MAIN PROGRAM
C
         WIDE(1)=FERST
         DEFLEC=FERST
         ADJ(1)=FIRST
         RANGE=FIRST
         DIST=OTRG
C
C        IN ACCORDANCE WITH THE PROCEDURE, THE FIRST RANGE
C     SHIFT IS OF 200 METERS.  DEFLECTION SHIFTS ARE ONTO LINE.
C
         SHIFT=200
       1 IF(ABS(ADJ(J)/WIDE(J)).LT..36397) SHIFT=0
         CORECT=RDOFF(-ERRFCN(DIST,WIDE(J)))
         DEFLEC=DEFLEC+CORECT
         IF(ADJ(J).LT.0.0) GO TO 2
         LESS=.FALSE.
         RANGE=RANGE-SHIFT
         GO TO 3
       2 LESS=.TRUE.
         RANGE=RANGE+SHIFT
C
C        WHEN THE SHIFT IN RANGE IS 50 METERS, FIRE FOR EFFECT
C     PHASE IS ENTERED.
C
       3 IF(SHIFT.EQ.50) GO TO 6
         IF(SHIFT.EQ.100.AND.PER.GT.38.0)GO TO 6
         J=J+1
C
C        BY USING THE SUBROUTINE"RAN",THE STRIKE OF ROUNDS IS
C     DETERMINED BY DISTRIBUTING THE FALL OF SHOT ABOUT THE
C     POINT OF AIM AS A BIVARIATE NORMAL DISTRIBUTION WITH
C     PARAMETERS BASED ON THE PROBABLE ERRORS.  THE N(0,1) RAN-
C     DOM DEVIATE RETURNED FROM "RAN" IS CONVERTED FOR USE BY
C     APPLYING THE FORMULA X=(NUMBER-MEAN)*STANDARD DEVIATION.
C
       4 ADJ(J)=(RAN(0))*PER/.6745+RANGE
         SENSE(J)=ERRFCN(DIST,ADJ(J))
         WIDE(J)=(RAN(0))*PED/.6745+DEFLEC
```

```
C
C      LOGICAL IF STATEMENTS AS THE ONE FOLLOWING ARE USED TO
C   DETERMINE THE RELATIVE SENSINGS OF THE ROUNDS.
C
       IF(SHIFT.EQ.0) GO TO 888
C
       IF(SHIFT.NE.200)GO TO 5
       IF(ADJ(J).LT.0.0.AND.LESS.OR.ADJ(J).GT.0.0.AND..NOT.LE
      1SS) GO TO 1
C
C      HALVE THE SHIFT, REDUCING THE BRACKET.
C
     5 SHIFT=SHIFT/2
       GO TO 1
C
C      OBSERVER DETERMINES SHIFT FOLLOWING DOUBTFUL SENSING.
C
   888 IF(ABS(SENSE(J)).GT.100) SHIFT=200
       IF(ABS(SENSE(J)).LE.100) SHIFT=100
       IF(ABS(SENSE(J)).LE.50.AND.J.GT.3.0) SHIFT=50
       GO TO 1
C
C      ENTERING FIRE FOR EFFECT.
C
     6 FFE(N)=(RAN(0))*PER/.6745+RANGE
     7 IF(FFE(N).LT.0.0) GO TO 8
       LESS=.FALSE.
       IUSE1=FFE(N)
C
C      IN FFE PHASE SHIFT ONE FORK ( FOUR PER ) UNTIL
C   AN OPPOSITE RANGE SENSING IS ACHIEVED
C
       RANGE=RANGE-(4*PER)
       GO TO 9
     8 LESS=.TRUE.
       IUSE2=FFE(N)
       RANGE=RANGE+(4*PER)
C
C      THE FOLLOWING REFERS TO DEFLECTION CORRECTION.
C   DEFLECTION IS CORRECT WHEN HALF-S BRACKET IS SPLIT.
C
     9 HALFS=2*RN/1000
       CHECK=ABS(DEFLEC)
       IF(CHECK.LT.HALFS.AND.N.GT.1)GO TO 93
C
C      IF NOT WITHIN HALF-S, CONTINUE TO CONSIDER DEFLECTION.
C
       WIDFFE(N)=(RAN(0))*PED/.6745+DEFLEC
       IF(WIDFFE(N).LT.0)GO TO 92
       DEFLEC=DEFLEC-HALFS
       GO TO 91
    92 DEFLEC=DEFLEC+HALFS
       GO TO 91
    93 K=N
    91 N=N+1
       FFE(N)=(RAN(0))*PER/.6745+RANGE
       IF(FFE(N).LT.0.0.AND.LESS.OR.FFE(N).GT.0.0.AND..NOT.LE
      ASS) GO TO 7
       IF(FFE(N).LT.0.0)GO TO 10
C
C      AFTER A FORK BRACKET IS ESTABLISHED, SHIFT 2 PER.
C
       IUSE1=FFE(N)
       RANGE=RANGE-(2*PER)
       GO TO 11
    10 IUSE2=FFE(N)
       RANGE=RANGE+(2*PER)
```

```
C
C      THE FOLLOWING ROUNDS WILL BE USED IN COMPUTING THE AD-
C   JUSTED ELEVATION.  THEIR LOCATION WILL BE RECORDED BOTH
C   AS ESTIMATED BY THE PROCEDURE AND AS GENERATED BY THE
C   MODEL.
C
   11 CENTER=RANGE
  999 I=I+1
      N=N+1
      FFE(N)=(RAN(0))*PER/.6745+RANGE
C
C      IF DEFLECTION IS STILL NOT CORRECT, CONTINUE TO
C   COMPUTE IT.
C
      IF (K.GT.0) GO TO 94
      WIDFFE(N)=RAN(0)*PED/.6745+DEFLEC
      IF (WIDFFE(N).LT.0)GO TO 95
      DEFLEC=DEFLEC-HALFS
      GO TO 96
   95 DEFLEC=DEFLEC+HALFS
   96 CHECK=ABS(DEFLEC)
      IF(CHECK.GT.HALFS)GO TO 94
      K=N
   94 IF(FFE(N).LT.0)GO TO 12
      OVER=OVER+1
      GO TO 13
   12 SHORT=SHORT+1
   13 IUSE(I)=FFE(N)
C
C     IF THREE ROUNDS HAVE BEEN FIRED AT THE CENTER ELEVATION
C   THE PREPONDERANCE IS COMPUTED AND A SHIFT OF 2 PER MADE
C   AWAY FROM THAT PREPONDERANCE.  A TOTAL OF SIX ROUNDS, TWO
C   PER APART ARE USED IN THE FINAL COMPUTATION OF ADJUSTED
C   ELEVATION.
C
      IF(I.EQ.3.OR.I.EQ.6)GO TO 14
      GO TO 999
   14 IF(I.EQ.6)GO TO 17
      I=I+1
C
C      DETERMINE PREPONDARANCE.
C
      IF(OVER.GT.SHORT)GO TO 15
      RANGE=RANGE+(2*PER)
      IUSE(I)=IUSE1
      OVER=OVER+1
      GO TO 16
   15 RANGE=RANGE-(2*PER)
      IUSE(I)=IUSE2
      SHORT=SHORT+1
   16 OTHER=RANGE
      GO TO 999
C
C      FIRING OF REGISTRATION IS COMPLETE.  ADJUSTED ELEVA-
C   TION AND DEFLECTION ARE NOW COMPUTED  USING A PREPONDER-
C   ANCE FORMULA.
C
   17 CORR=(SHORT-OVER)*PER*2/(SHORT+OVER)
      ADJCI=((CENTER+OTHER)/2)+CORR
C
C      MISS DISTANCE IN RANGE AND DEFLECTION IS COMPUTED, AND
C   CONVERTED TO RADIAL MISS DISTANCE
C
      MISDIS=SQRT(ADJCI**2+CHECK**2)
C
      IADD=J+N
      RETURN
      END
```

```
C     THIS SUBROUTINE  MODELS THE NEW PRECISION REGISTRATION
C   PROCEDURE CESIGNED BY THE FIELD ARTILLERY SCHOOL.
C

      SUBROUTINE NEW
      REAL MISDIS,OTRG
      LOGICAL LESS
      DIMENSION ADJ(50),FFE(50),WIDE(50),WIDFFE(50),SENSE(50
      DIMENSION DSENSE(50)
      COMMON TABLE(50,6),OTRG,FIRST,FERST,RN,MISDIS,IADD,PER
     1,PED
C
C     ZERO ALL ARRAYS
C
      DO 99 I=1,50
      ADJ(I)=0
      FFE(I)=0
      WIDE(I)=0
      SENSE(I)=0
      DSENSE(I)=0
   99 WIDFFE(I)=0
      DO 77 I=1,50
      DO 77 J=1,6
   77 TABLE(I,J)=0
      J=1
      IQUIT=0
      MIX=0
C
C     THE FIRST ROUND IS TAKEN AS SENT FROM THE MAIN PROGRAM
C
      WIDE(1)=FERST
      DEFLEC=FERST
      ADJ(1)=FIRST
      RANGE=FIRST
      DIST=OTRG
C
C     TEST IS THE SHIFT OF THE FIRST TWO ROUNDS IN THE FIRE
C   FOR EFFECT PHASE.
      TEST=25
      IF(PER.GT.25.0) TEST=50
C
C     IN ACCORDANCE WITH THE PROCEDURE, THE FIRST RANGE
C   SHIFT IS OF 200 METERS.  DEFLECTION SHIFTS ARE ONTO LINE.
C
   67 SHIFT=200
    1 IF(ABS(ADJ(J)/WIDE(J)).LT..36397) SHIFT=0
      CORECT=RDOFF(-ERRFCN(DIST,WIDE(J)))
      DEFLEC=DEFLEC+CORECT
      IF(ADJ(J).LT.0.0) GO TO 2
      LESS=.FALSE.
      RANGE=RANGE-SHIFT
      GO TO 3
    2 LESS=.TRUE.
      RANGE=RANGE+SHIFT
    3 IF(SHIFT.EQ.TEST) GO TO 6
      J=J+1
    4 ADJ(J)=(RAN(0))*PER/.6745+RANGE
      SENSE(J)=ERRFCN(DIST,ADJ(J))
      WIDE(J)=(RAN(0))*PED/.6745+DEFLEC
      IF(SHIFT.EQ.0) GO TO 888
      IF(SHIFT.NE.200)GO TO 5
      IF(ADJ(J).LT.0.0.AND.LESS.OR.ADJ(J).GT.0.0.AND..NOT.LE
     1SS) GO TO 1
C
C     HALVE THE SHIFT, REDUCING THE BRACKET.
C
    5 SHIFT=SHIFT/2
      GO TO 1
```

```
C
C     OBSERVER DETERMINES SHIFT FOLLOWING DOUBTFUL SENSING.
C
  888 IF(ABS(SENSE(J)).GT.100) SHIFT=200
      IF(ABS(SENSE(J)).LE.100) SHIFT=100
     *IF(ABS(SENSE(J)).LE.50.AND.J.GT.3.0) SHIFT=50
      GO TO 1
C
C     FIRE FOR EFFECT PHASE IS ENTERED
C
    6 CONTINUE
C
C     AN ALGORITHM IS ESTABLISHED TO REPEATEDLY FIRE ROUNDS
C   ACCORDING TO THE RULES OUTLINED IN THE NEW PROCEDURE.
C   RESULTS OF ALL COMMANDS, SENSINGS AND DID-HIT DATA ARE
C   STORED IN AN ARRAY CALLED TABLE.
C
      DO 1000 N=1,50
      TABLE(N,3)=RANGE
      FFE(N)=RAN(0)*PER/.6745+RANGE
      TABLE(N,4)=FFE(N)
      WIDFFE(N)=RAN(0)*PED/.6745+DEFLEC
      TABLE(N,6)=WIDFFE(N)
      SENSE(N)=ERRFCN(OTRG,FFE(N))
      SENSE(N)=IFIX(SENSE(N))
      TABLE(N,5)=SENSE(N)
      DSENSE(N)=ERRFCN(OTRG,WIDFFE(N))
      DSENSE(N)=IFIX(DSENSE(N))
      IF(ABS(FFE(N)/WIDFFE(N)).LT..36397) GO TO 13
      IF(SENSE(N).GT.0.0) TABLE(N,2)=1.0
      IF(SENSE(N).LE.0.0) TABLE(N,1)=1.0
      IF(N.LT.2) GO TO 1000
      IF(N.EQ.5) MIX=0
      IF(N.GE.4) GO TO 75
    7 IF(SENSE(N).GT.0.0.AND.SENSE(N-1).GT.0.0) GO TO 10
      IF(SENSE(N).LT.0.0.AND.SENSE(N-1).LT.0.0) GO TO 11
      IF(N.EQ.2) MIX=1
      IF(N.EQ.2) GO TO 12
      IF(N.LT.5.AND.MIX.EQ.1) GO TO 1000
      IF(N.GE.3) GO TO 13
C
C     A MINIMUM OF 4 ROUNDS HAVE BEEN FIRED IN THIS PHASE,
C   CALL SUBROUTINE SCAN TO DETERMINE IF THE CRITERIA TO
C   END THE MISSION IS SATISFIED.
C
   75 CALL SCAN(IQUIT,IR10,IR20,IR1S,IR2S,TEST)
C
C     IF CRITERIA IS SATISFIED, GO THE THE END OF MISSION
C   SUBROUTINE TO COMPUTE THE FINAL COMMANDS, OTHERWISE
C   CONTINUE FIRING ACCORDING TO THE ALGORITHM.
C
      IROW=N
      IF(IQUIT.EQ.1) GO TO 85
      GO TO 7
   10 IF(MIX.EQ.1) GO TO 1000
      RANGE=RANGE-TEST
      IF(N.EQ.2) GO TO 12
      GO TO 13
   11 IF(MIX.EQ.1) GO TO 1000
      RANGE=RANGE+TEST
      IF(N.EQ.2) GO TO 12
   13 X=RDOFF(DSENSE(N))
      GO TO 14
   12 X=RDOFF((DSENSE(N)+DSENSE(N-1))/2.0)
   14 DEFLEC=DEFLEC-X
 1000 CONTINUE
   85 CALL ECM(J,IROW,IR10,IR20,IR1S,IR2S)
      RETURN
      END
```

```
C
C        THIS SUBROUTINE SCANS PREVIOUSLY FIRED ROUNDS TO DE-
C     TERMINE IF THERE ARE TWO PAIRS OF POSITIVE SENSINGS
C     WITHIN A 25 METER BRACKET
C
C

      SUBROUTINE SCAN(IQUIT,IR1O,IR2O,IR1S,IR2S,TEST)
      REAL MISDIS,OTRG
      COMMON TABLE(50,6),OTRG,FIRST,FERST,RN,MISDIS,IADD,PER
     1,PED
C
C     FIRST CHECK FOR TWO OVERS
C
      IQUIT=0
      ICOUNT=0
      DO 100 I=1,50
      IF(TABLE(I,2).NE.1.0) GO TO 100
      ICOUNT=ICOUNT+1
      IF(ICOUNT.GE.2) GO TO 200
  100 CONTINUE
C
C     IF THERE ARE NOT TWO OVERS RETURN AND CONTINUE FIRING
C
      GO TO 6000
C
C     CHECK FOR TWO SHORTS
C
  200 ICOUNT=0
      DO 300 I=1,50
      IF(TABLE(I,1).NE.1.0) GO TO 300
      ICOUNT=ICOUNT+1
      IF(ICOUNT.GE.2) GO TO 400
  300 CONTINUE
C
C     IF THERE ARE NOT TWO SHORTS RETURN AND CONTINUE FIRING
C
      GO TO 6000
C
C     TWO OVERS AND TWO SHORTS EXIST
C
  400 DO 500 I=1,50
      IF(TABLE(I,2).NE.1.0) GO TO 500
      K=I+1
      DO 600 J=K,50
      IF(TABLE(J,2).NE.1.0) GO TO 600
      IF(TABLE(I,3).NE.TABLE(J,3))GO TO 600
      DIST1=TABLE(I,3)
      DO 700 L=1,50
      IF(TABLE(L,1).NE.1.0) GO TO 700
      M=L+1
      DO 800 N=M,50
      IF(TABLE(N,1).NE.1.0) GO TO 800
      IF(TABLE(L,3).NE.TABLE(N,3))GO TO 800
      DIST2=TABLE(L,3)
      IF(ABS(DIST1-DIST2).GT.TEST) GO TO 800
      IR1O=I
      IR2O=J
      IR1S=L
      IR2S=N
      GO TO 1000
C
C        IF TWO PAIRS WITHIN TEST METERS HAVE BEEN FOUND GO TO
C      THE EOM SUBROUTINE TO SEND FINAL CORRECTIONS.
C
  800 CONTINUE
  700 CONTINUE
  600 CONTINUE
  500 CONTINUE
```

```
C
C      LOOK FOR TWO PAIRS OF MIXED SPOTTINGS WITHIN TEST MTRS
C
 2000 DO 1500 I1=1,50
      IF(TABLE(I1,2).NE.1.0) GO TO 1500
      DO 1510 J1=1,50
      IF(TABLE(J1,1).NE.1.0) GO TO 1510
      IF(TABLE(J1,3).NE.TABLE(I1,3)) GO TO 1510
      DIST1=TABLE(J1,3)
      M=I1+1
      DO 1520 K1=M,50
      IF(TABLE(K1,2).NE.1.0) GO TO 1520
      DO 1530 L1=1,50
      IF(TABLE(L1,1).NE.1.0) GO TO 1530
      IF(L1.EQ.J1) GO TO 1530
      IF(TABLE(K1,3).NE.TABLE(L1,3)) GO TO 1530
      DIST2=TABLE(K1,3)
      IF(ABS(DIST1-DIST2).GT.TEST) GO TO 1530
      IR1O=I1
      IR2O=K1
      IR1S=J1
      IR2S=L1
      GO TO 1000
C
C      IF TWO MIXED PAIRS WITHIN TEST METERS HAVE BEEN FOUND
C   GO TO EOM SUBROUTINUE TO SEND FINAL CORRECTIONS.
C
 1530 CONTINUE
 1520 CONTINUE
 1510 CONTINUE
 1500 CONTINUE
      GO TO 6000
 1000 IQUIT=1
 6000 RETURN
      END
```

```
C
C     THIS SUBROUTINE COMPUTES THE MISS DISTANCE BASED ON THE
C  OBSERVERS' CORRECTIONS TO THE LAST ROUND FIRED.
C

      SUBROUTINE EOM(J,IROW,IR1O,IR2O,IR1S,IR2S)
      REAL MISDIS,OTRG
      COMMON TABLE(50,6),OTRG,FIRST,FERST,RN,MISDIS,IADD,PER
     1,PED
C
C     COMPUTE THE AVERAGE RANGE TO THE TWO OVERS.
C
      X=(TABLE(IR1O,4)+TABLE(IR2O,4))/2
C
C     COMPUTE THE AVERAGE RANGE TO THE TWO SHORTS.
C
      Y=(TABLE(IR1S,4)+TABLE(IR2S,4))/2
C
C     THE FORWARD OBSERVER ESTIMATES THE RANGE OF OVERS.
C
      R=(TABLE(IR1O,5)+TABLE(IR2O,5))/2
C
C     THE FORWARD OBSERVER ESTIMATES THE RANGE OF SHORTS.
C
      S=(TABLE(IR1S,5)+TABLE(IR2S,5))/2
C
C     THE OBSERVER MAKES FINAL DEFLECTION CORRECTIONS.
C
      CORECT=-ERRFCN(OTRG,TABLE(IROW,6))
C
C     OBSERVER MAKE CORRECTIONS BASED TWO PAIRS OF ROUNDS.
C
      IF(TABLE(IR1O,3).EQ.TABLE(IR1S,3)) GO TO 77
      GO TO 10
   77 RGACT=(X+Y)/2
      GO TO 16
   10 IF(TABLE(IROW,5).GT.0.0) GO TO 12
      IF(S.LE.-37.5) SHIFT=50
      IF(S.GT.-37.5) SHIFT=25
      IF(S.GT.-17.5) SHIFT=10.
      IF(S.GT.-5.0) SHIFT=0.
      GO TO 15
      IF(R.GE.37.5) SHIFT=-50
   12 IF(R.LT.37.5) SHIFT=-25
      IF (R.LT.17.5) SHIFT=-10
      IF(R.LT.5.0) SHIFT=0
   15 RGCORR=SHIFT
C
C     MISS DISTANCE IN RANGE IS COMPUTED FROM THE ACTUAL
C   LOCATION OF THE LAST PAIR OF ROUNDS.
C
      IF(TABLE(IROW,4).GT.0.0) GO TO 14
      RGACT=Y+RGCORR
      GO TO 16
   14 RGACT=X+RGCORR
C
C     MISS DISTANCE IN DEFLECTION IS COMPUTED FROM THE
C  ACTUAL LOCATION OF THE LAST ROUND.
C
   16 DFACT=TABLE(IROW,6)+CORECT
C
C     RADIAL MISS DISTANCE IS COMPUTED
C
      MISDIS=SQRT(ABS(RGACT)**2+ABS(DFACT)**2)
C
C     NUMBER OF ROUNDS FIRED
C
      IADD=J+IROW
      RETURN
      END
```

```
C
C     THIS SUBROUTINE IS TAKEN DIRECTLY FROM THE IBM
C  LIBRARY OF SUBROUTINES.
C
C     THE SIMULATION MODEL USED WITH THIS THESIS USED ONLY
C  OPTION 3.
C     ..........................................................
C        SUBROUTINE TTEST
C     ..........................................................
C
C
      SUBROUTINE TTEST (A,NA,B,NB,NOP,NDF,ANS)
C
C
C        SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C           NONE
      REAL A,B
      DIMENSION A(1000),B(1000)
C
C     INITIALIZATION
C
      NDF=0
      ANS=0.0
C
C     CALCULATE THE MEAN OF A
C
      AMEAN=0.0
      DO 110 I=1,NA
  110 AMEAN=AMEAN+A(I)
      FNA=NA
      AMEAN=AMEAN/FNA
C
C     CALCULATE THE MEAN OF B
C
  115 BMEAN=0.0
      DO 120 I=1,NB
  120 BMEAN=BMEAN+B(I)
      FNB=NB
      BMEAN=BMEAN/FNB
C
      IF(NOP-4) 122, 125, 200
  122 IF(NOP-1) 200, 135, 125
C
C     CALCULATE THE VARIANCE OF A
C
  125 SA2=0.0
      DO 130 I=1,NA
  130 SA2=SA2+(A(I)-AMEAN)**2
      SA2=SA2/(FNA-1.0)
C
C     STANDARD DEVIATION OF A
C
      SDA=SQRT(SA2)
C
C     CALCULATE THE VARIANCE OF B
C
  135 SB2=0.0
      DO 140 I=1,NB
  140 SB2=SB2+(B(I)-BMEAN)**2
      SB2=SB2/(FNB-1.0)
C
C     STANDARD DEVIATION OF B          E
C
      SDB=SQRT(SB2)
C
      GO TO (150,160,170,180), NOP
```

```
C
C        OPTION 1
C
  150 ANS=((BMEAN-AMEAN)/SQRT(SB2))*SQRT(FNB)
      NDF=NB-1
      GO TO 200


C
C        OPTION 2
C
  160 NDF=NA+NB-2
      FNDF=NDF
      S=SQRT(((FNA-1.0)*SA2+(FNB-1.0)*SB2)/FNDF)
      ANS=((BMEAN-AMEAN)/S)*(1.0/SQRT(1.0/FNA+1.0/FNB))
      GO TO 200


C
C        OPTION 3
C
  170 ANS=(BMEAN-AMEAN)/SQRT(SA2/FNA+SB2/FNB)
      A1=(SA2/FNA+SB2/FNB)**2
      A2=(SA2/FNA)**2/(FNA+1.0)+(SB2/FNB)**2/(FNB+1.0)
      NDF=A1/A2-2.0+0.5
      GO TO 200


C
C        OPTION 4
C
  180 SD=0.0
      D=BMEAN-AMEAN
      DO 190 I=1,NB
  190 SD=SD+(B(I)-A(I)-D)**2
      SDBAR=SQRT(SD/((FNB-1.0)*FNB))
      ANS=D/SDBAR
      NDF=NB-1
C
  200 RETURN
      END
```

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ABSTRACT

This thesis is addressed to the problem of determining if the precision registration procedure currently being utilized by the Field Artillery is as accurate and economical as a procedure that has recently been proposed by the Gunnery Department at Fort Sill, Oklahoma. A comparison of the two procedures was performed through the use of a computer simulation model. Data from the simulation was analyzed and conclusions were drawn regarding the relative accuracy and economy of the two procedures.

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